Anim Cogn (2003) 6 : 141–148
DOI 10.1007/s10071-003-0176-9

ORIGINAL ARTICLE

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Joystick acquisition in tufted capuchins (*Cebus apella*)

Received: 10 September 2001 / Revised: 2 June 2003 / Accepted: 6 June 2003 / Published online: 28 June 2003

Abstract A number of nonhuman primate species have demonstrated the ability to use a joystick to control a cursor on a computer screen, yet the acquisition of this skill has not been the focus of systematic inquiry. Here, we examined joystick acquisition in four tufted capuchins under two directional relationships of joystick movement and resultant cursor displacement, isomorphic and inverted. To document the natural history of the acquisition of this skill, we recorded the development of visual tracking of the cursor and body tilting. Rates of acquisition were comparable between the two conditions. After mastering the task in one condition, subjects remastered the task at an accelerated rate in the opposing condition. All subjects significantly increased or maintained high proportions of cursor tracking throughout acquisition. All subjects demonstrated a postural tilt while moving the cursor from the mid-phase of acquisition through task mastery. In the isomorphic condition, all subjects tilted significantly more often in the direction of goal location than in the opposite direction. In three of the four series of tilting that were scored for subjects in the inverted condition, tilting occurred significantly more often toward the direction of goal location than the direction of required hand movement. Together these findings suggest that body tilting participates in the organization of directional movement of the cursor rather than reflecting merely the motoric requirements of the task (to manipulate a joystick).

Keywords Skill acquisition · Joystick · Body tilting · *Cebus apella*

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Introduction

We document the process of skill development in four tufted capuchin monkeys (*Cebus apella*) learning to use a joystick to control a cursor on a computer monitor. Mastering a joystick is an interesting problem in skill development. In joystick systems, the actor is necessarily displaced spatially from the important elements of the task: the actor manipulates the joystick in one area to cause movement of the cursor in another area of the visual field (i.e. the monitor; Rumbaugh et al. 1989). Therefore, unlike most tasks worked in three dimensions, the actor never comes in physical contact with the cursor, nor with the “goal” region to which the cursor must be moved. Additionally, actors must learn to move the joystick with the hand, an action that occurs in three dimensions, while viewing the results of this movement on a two-dimensional computer monitor. This three-dimensional/two-dimensional interface is completely novel to nonhuman subjects; all their previous life experiences have involved action on objects in three dimensions.

The question subsequently arises: how does a monkey (or a human) learn to move a joystick to control a spatially displaced cursor that moves only in two dimensions? Individuals of a number of nonhuman primate species have demonstrated the ability to use a joystick (Andrews 1993; Andrews and Rosenblum 1993; Filion et al. 1994; Hopkins 1991; Jorgensen et al. 1993; Richardson et al. 1990; Vauclair and Fagot 1993), yet the acquisition of this skill has not been the focus of systematic inquiry.

To provide a natural history of skill development in this task, we divided acquisition into eight phases. We noted the number of trials faced by each subject prior to mastering each phase of skill. We documented shifts in visual tracking of the cursor on the monitor by subjects across these phases. To investigate how the subjects learned to link their movements of the joystick with the resultant displacement of the cursor in two dimensions, we used two different joystick/cursor directional relationships. In the first condition (isomorphic) the direction of joystick movement and resultant cursor displacement was the same. In the inverted condition the directional relationship between movement of the joystick and cursor was 180° opposed. Two subjects, after mastering the task in the inverted condition, relearned the skill in the isomorphic condition. Due to concurrent research needs, the two subjects that had originally learned the task in the isomorphic condition did not face the reversal (to the inverted condition).

We had previously observed that capuchin monkeys proficient with the joystick tilt their bodies in a distinctive manner (lateral movement of the head and torso) while manipulating the joystick (C.M. Filion et al., unpublished data). This body tilt appears similar in form and context to that demonstrated by humans playing videogames (personal observation). Whereas tilting behavior in this context is quite familiar to us, we have been unable to find a report in the scientific literature of humans tilting the torso while playing video games or completing other computerized tasks. Kluver (1933), however, noted a similar phenomenon in a capuchin monkey "drawing" with chalk or a nail on a floor: "the whole body, and especially the head, often participated in the 'drawing' movements" (p. 304). In Kluver's monkey, the tilting or head movements were not as clearly associated with an effort to control a distal or moving object as they appear to be in manipulating a joystick to control a cursor. Explorations of the perceptual motor workspace via self-generated movements could aid in learning perceptually novel movement–outcome relationships. Tilting may help actors in realizing directional relationships within the perceptual motor workspace either by moving the head toward the goal (changing the distance between the head and the goal region) or by enlarging the actor's movement (of the joystick) and thus making it more salient during the act of moving the joystick. We focus our analysis in this report on the appearance of tilting during acquisition and its directional relation to cursor movement.

Research on the use of controls in a flight simulator suggests that controls are easier to use when movements are directionally compatible with the corresponding display movements (Poulton 1974). Researchers utilizing joystick-testing systems have also found that human learning is facilitated by a direct relationship between controller and display movement (Poulton 1966). Similarly, in nonhumans, Jorgensen (1995) found that capuchin monkeys and chimpanzees took longer to complete trials of a modified version of the CHASE task, in which the subject must bring a cursor in contact with a moving target, when the relationship between joystick movement and cursor displacement was randomized than when this relationship was isomorphic. Along a similar line of investigation, Menzel et al. (1985) found that when chimpanzees use a televised image to reach for items that were obstructed from view, they had significantly more difficulty with the task when the image was reversed, inverted, or both reversed and inverted than when viewing an isomorphic image. Thus, tasks appear to be more difficult to complete when the motor program and resultant alterations to the environment by the body are not isomorphic (i.e. when perception and action do not align). This seems logical because inverted relationships between movement and outcome are quite rare in the three-dimensional world. We therefore predicted that subjects initially assigned to the isomorphic condition would acquire skill with the joystick at a faster rate than would those initially assigned to the inverted condition.

Learning the association between joystick manipulation and cursor position and learning the directional relationship present between the two both require visual tracking of the cursor. Incorporation of the cursor's movement into guidance of action should be manifest by visual tracking of the cursor while it moves across the screen. Thus, our second prediction was that each subject would track the cursor more during its displacement as it achieved increasing mastery of the joystick. Since attention to the display would already be in place when subjects encountered the reversed joystick/cursor relationship, our third prediction was that subjects would visually track the cursor significantly more at the four-sided criterion following the reversal than they had at the four-sided criterion in the initial inverted condition. Fourth, because these subjects had learned to monitor the visual display as well as to control the joystick prior to reversal, we expected that they would be able to transfer knowledge of these two key components of the task under the new conditions. Therefore, we predicted that subjects would acquire skill in the isomorphic condition following reversal more quickly than they had in the inverted condition and more quickly than those initially assigned to the isomorphic condition.

Finally, we predicted that these subjects would develop a pronounced body tilt during the course of joystick mastery as seen from informal observation of humans and as previously noted in capuchins (C.M. Filion et al., unpublished data). If body tilts reflect an effort to control the movement of the cursor, we expected that significantly more tilts would occur in the direction of the goal location than in the direction of required joystick movement in all conditions. If the tilt enlarges the movement of the actor, then we expected tilts to occur in the direction of required joystick movement in all conditions.

Our research has three aims. First, we provide a natural history of skill development with attention to behavioral changes that accompany changes in success and efficiency in controlling the cursor. Specifically, we document the development of visual tracking of cursor movement on the monitor and the development of body tilting while monitoring the cursor. Second, we address the consequences of an isomorphic versus an inverted relationship between joystick movement and cursor displacement for skill development. Finally, we address the subjects' adjustment to new parameters of movement following a reversal of this joystick/cursor relationship.

Methods

Subjects and housing

The subjects of this study were four male tufted capuchins (*Cebus apella*): Leo, Nick, Mickey, and Solo (aged 5–7 years). Subjects

Fig. 1 Joystick testing station

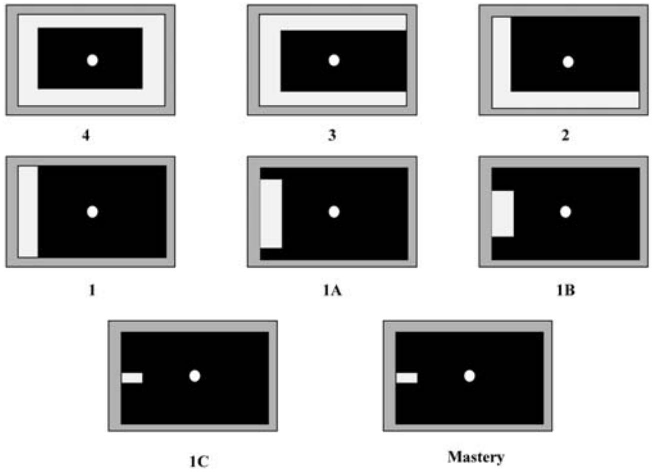

Fig. 2 Titrations of the SIDES task

were pair housed in indoor cages at the University of Georgia. They were fed Lab Diet monkey chow twice daily and various fruits once a day. Water was available ad libitum. Testing took place outside of the homecage in a separate testing room. Video and computer equipment was controlled from a room adjacent to this testing room.

Apparatus

The testing room contained two testing stations. Each station consisted of a clear Plexiglas and metal testing cage (64×47×78 cm) placed in front of a Plexiglas-covered computer monitor (28×20 cm), a Kraft KC3 joystick, Noyes sugar pellet dispenser, and stereo speaker. An armhole (5.84 cm in diameter), providing full range of motion, was centered in the front Plexiglas panel of the cage, set up approximately 10 cm from the joystick and therefore 25 cm from the monitor itself. A perch in front of the armhole permitted animals to sit or stand while manipulating the joystick. The joystick required a deflection of 10° to initiate cursor movement. Once movement of the cursor began, it continued at a constant speed of 5 cm/s until the deflection of the joystick was less than 10°. A Panasonic video camera (model XL-CL700) mounted above the computer monitor provided images of the subject's face and body during testing (see Fig. 1). Additional cameras in the computer room recorded the images presented on the monitor of each testing station. Signals from these four cameras were routed through a Panasonic QuadPlex to allow them to record simultaneously to a single VHS tape.

Subjects were presented with the SIDES task, the first in a series of joystick-mediated tasks developed at the Language Research Center of Georgia State University (Richardson et al. 1990; Rumbaugh et al. 1989). The goal of the SIDES task was to manipulate the joystick to bring a cursor in contact with a highlighted region at the margin of the computer monitor. It began with all 4 margins of the monitor highlighted. The task was self-paced such that the subject's performance controlled progress through the task. A trial was successfully completed when the cursor was moved into the goal region. The program randomized the position of the goal regions across trials. After the successful completion of five trials with four highlighted margins, the goal area titrated down to three highlighted sides. With increasing mastery, the goal region continued to reduce to two sides, one side, 1A (approximately two thirds of a margin), 1B (approximately one third of a margin), and 1C (an area slightly larger than the cursor itself; see Fig. 2). When the cursor contacted a wall outside of the goal region it would stop at that point until the cursor was deflected away from that margin. The program returned to the previous titration of the goal region when the subject experienced difficulty on a titration (i.e. exceeded 20-s time limit for average trial completion for the block and/or dropped out of trials by not contacting the joystick for 45 s).

Procedure

Subjects were given the opportunity to work on the SIDES task twice a week for approximately 15–30 min each session. Pairmates were tested simultaneously, each animal at its own station, with one experiencing an isomorphic relationship between joystick movement and resultant displacement of the cursor on the monitor, and the other initially experiencing an inverted relationship. Leo and Mickey were initially assigned to the isomorphic condition. In this condition, manipulation of the joystick in a particular direction resulted in movement of the cursor in that same direction. Thus, when the joystick was manipulated to the left, the cursor moved to the left on the monitor. Nick and Solo were initially assigned to the inverted condition. In this condition, manipulation of the joystick resulted in movement of the cursor on the monitor in a direction 180° opposed to that of joystick manipulation. Thus, movement of the joystick to the left displaced the cursor to the right side of the monitor. Upon achieving mastery of the inverted condition, Nick and Solo were presented with the isomorphic condition and were trained on the SIDES task following the same procedures as above (see Table 1). Successful completion of a trial by placing the cursor in the highlighted region resulted in a tone sounding, a green sunburst display on the computer monitor, and the delivery of a Noyes sugar pellet and/or hand delivery of a piece of nut or dried fruit by the experimenter.

Training took place over an 18-month period. Data from each trial were recorded by the computer and saved to disk by the ex-

Table 1 Assignment to conditions. *Isomorphic* Direction of joystick movement and cursor displacement are the same. *Inverted* Direction of joystick movement and cursor displacement are 180° opposed

Subject	First joystick relationship	Second joystick relationship
Leo	Isomorphic	None
Mickey	Isomorphic	None
Nick	Inverted	Isomorphic
Solo	Inverted	Isomorphic

perimenter at the end of each testing session. VHS recordings of the testing sessions were digitized using the Broadway software package and selected trials were burned to CDs. Data were collected from these CDs using the Observer Video-Pro (Noldus Corp.), a software package for the analysis of observational data.

Data scoring

Video records were scored for three elements of joystick acquisition: trial completion, cursor tracking, and body tilting as judged by two observers. The percentage agreement for these two observers examining trial completion for two subjects was 100%. The percentage agreement over 30 trials for two subjects was 100% for cursor-tracking data with a maximum time discrepancy of ± 0.1 s, and 100% for frequency and direction of body tilts.

Acquisition

Rate of acquisition was determined by recording the total number of trials presented prior to first achieving specific criteria at each titration. We defined this criterion to be successful completion of 9 out of 10 consecutive trials for the particular titration. Criterion for joystick acquisition, or mastery of the SIDES task, was defined as successful completion of 18 out of 20 consecutive trials at the 1C titration following attainment of mastery on all prior titrations. In these 18 trials, the goal region was present on each margin at least two times and the subject could not bring the cursor in contact with the margin of the monitor outside of the highlighted goal region on more than one occasion per trial.

Cursor tracking

For each subject in each condition, the first 25 completed trials at mastery of each titration and upon joystick acquisition (including the 10 in which mastery was achieved) were scored for cursor tracking using frame-by-frame analysis of digitized images. We defined cursor tracking as the proportion of total trial duration in which the subject's pupils followed movement of the cursor on the monitor. Because the images from the computer monitor and frontal view of the subject were recorded simultaneously, we were able to examine a close-up image of the subject's face along with the image on the monitor that they were viewing in a simultaneous manner. With this setup it was possible to document the movement of the subject's pupil with the movement of the cursor. A timer was used to measure the total trial duration, defined as the period beginning with the first movement of the cursor and ending when the cursor entered the goal region. A second timer measured duration of cursor tracking. This timer only ran while the subject's pupil moved with the cursor and was paused when the cursor halted (since we were unable to determine at that time if the subject was tracking), the subject was not facing the monitor, or when the pupil did not move isomorphically with the cursor. Proportion of trials spent tracking was therefore calculated by dividing duration of cursor tracking by trial duration.

Body tilting

Using the digitized images and the Observer Video-Pro software, a frequency of body-tilting behavior was determined for each subject by scoring the total number of tilts per trial for 25 trials upon attainment of the four-sided criterion, one-sided criterion, and criterion for joystick mastery. The first 30 trials upon attaining joystick mastery (15 trials with the goal located on either side of the monitor) were scored to examine the frequency of tilting in each direction (left/right). We defined body tilting as movement of the body such that the ear opposite the direction of body movement passed over the midline of the subject's body (see Fig. 3). Total tilts in the left and right direction were scored for each trial by placing a vertical line overlay on the video screen and aligning it with the longitudinal axis of the torso at the body midline. The body midline was determined by using the forward-facing image of the subject prior to the beginning of each trial and placing the line on the subject's nose and between the hips. Each pass of the opposite ear over the midline in both the left and right direction was recorded. Movements of the ear over the midline when not facing the screen, or occurring during characteristic head bobs (typical of these monkeys in this test situation), were not counted as tilts. Location of the goal was recorded concurrently for analysis of the direction of tilt as a function of goal location and joystick/cursor relationship.

Fig. 3 Depiction of body tilting

Data analysis

To examine the prediction that joystick acquisition would occur more quickly in the subjects initially exposed to the isomorphic condition than those in the inverted condition, the numbers of trials presented prior to achieving each criterion for each subject were compared visually (the low *n* precluded the use of inferential statistics to compare the two conditions). Graphic depiction provided a means to examine individual trends in acquisition across the criteria and to examine differences between the conditions.

To test the prediction that cursor tracking would increase during acquisition for all subjects under the initial conditions we calculated the average proportion of a trial spent tracking for the first 25 trials following attainment of each criterion. Next, for each subject we conducted a sign test comparing the 25 trials from the four-sided criterion and 25 trials at criterion for joystick mastery. This was a one-tailed test and alpha was set at 0.05. The same procedure was used to test the prediction that subjects initially experiencing the inverted condition would track significantly more at criterion for the four-sided titration in the isomorphic condition following reversal than they did in the initial inverted condition.

To test the predictions that subjects that underwent reversal would master the isomorphic condition more quickly than they did the initial inverted condition and that they would master the isomorphic condition following reversal more quickly than the subjects initially placed in the isomorphic condition, trials to each criterion of joystick mastery were presented graphically for each subject. This allowed for a comparison within subjects of their initial and reversal performance as well as a comparison of the performance of both reversal subjects in the isomorphic condition to the performance of the two subjects that initially experienced that condition.

To examine the final prediction, that subjects would demonstrate body tilting during acquisition of the joystick, the frequency of tilts per trial for 25 trials for each subject at the four-sided titration, one-sided titration, and joystick mastery were examined. If tilting was present at joystick mastery, we examined the direction of tilts when the goal was located at the right and left of the monitor. This analysis was conducted using a two-tailed binomial test with alpha set at 0.05. The critical analysis to test this prediction was the examination of the tilting behavior of subjects in the inverted condition. Direction of goal location and direction of required hand movement are the same in the isomorphic condition but 180° opposed in the inverted condition. Thus, it is in the inverted condition that it can be determined if subjects tilt in accord with the direction of required hand movement or with goal location.

Results

All subjects reached criterion for joystick mastery in the initial condition. Subjects in the isomorphic and inverted conditions appeared to attain overall joystick mastery in equivalent numbers of trials (see Fig. 4). In the initial isomorphic condition, Leo acquired the task in 2,237 trials and Mickey did so in 3,195 trials. Nick and Solo initially experienced the inverted condition and acquired the task in 2,483 and 3,364 trials, respectively.

Three of four subjects significantly increased their proportion of trial spent visually tracking the cursor from criterion at the four-sided titration to joystick mastery (see Fig. 5). Leo maintained a fairly consistent level of tracking throughout acquisition (0.778 at four-sided titration and 0.791 at mastery). Mickey demonstrated a significant increase from 0.029 at the four-sided titration to 0.673 at mastery (sign test, $P<0.001$). Nick demonstrated a significant increase in cursor tracking from 0.00 at the four-sided titration to 0.900 at mastery (sign test, $P<0.001$). Solo increased cursor tracking significantly from 0.108 at the four-sided titration to 0.535 at mastery (sign test, $P<0.001$). Nick was tracking at 0.969 and Solo at 0.630 at criterion of the four-sided titration in the reversal isomorphic condition. Both subjects tracked significantly more at criterion for the four-sided titration of the reversal isomorphic condition than they did in the initial inverted condition (sign tests, $P<0.001$ for both subjects).

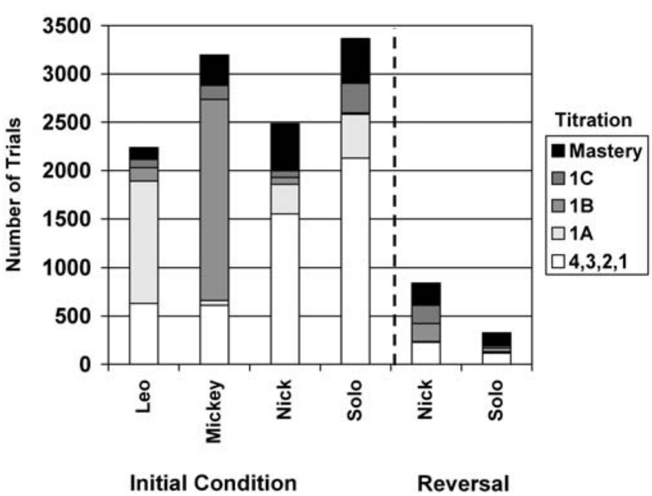

Fig. 4 Trials to criterion (isomorphic vs inverted) in the initial condition and reversal isomorphic condition

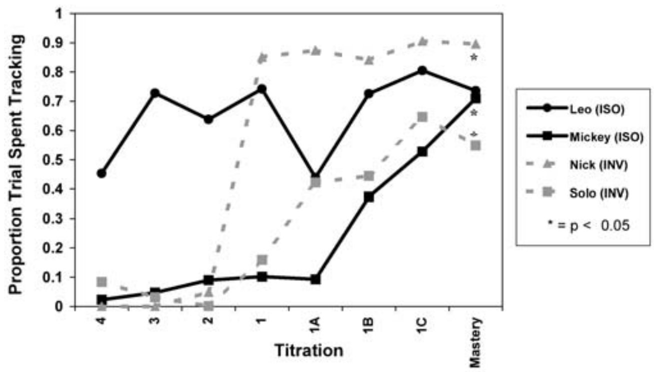

Fig. 5 Proportion of trial spent visually tracking the cursor in the initial condition (isomorphic or inverted)

Following reversal, Nick remastered the task in the isomorphic condition in 843 trials and Solo did so in 327 trials. Therefore, both subjects that underwent reversal from the initial inverted condition to the isomorphic condition mastered the second task far more quickly than the first. Additionally, both of these subjects mastered the isomorphic condition in fewer trials than did Leo and Mickey, who initially experienced this condition (see Fig. 4).

All subjects, in all conditions, demonstrated body tilting during the course of acquisition and at mastery (see Table 2). Tilting was absent in all subjects when first pre-

Table 2 Frequency of body tilts per trial

Subject	Condition	Four-sided titration	One-sided titration	Mastery
Leo	Isomorphic	0	0.24	0.64
Mickey	Isomorphic	0	0.08	1.4
Nick	Inverted	0	0.48	0.88
Solo	Inverted	0	0.36	0.64
Nick	Isomorphic	0.44	0.28	1.04
Solo	Isomorphic	0.2	1.2	0.8

Table 3 Direction of body tilts at joystick mastery

Subject	Condition	Goal location	Total tilts (in trials)	Tilts to goal	Binomial *P*-value
Leo	Isomorphic	R	15	15	<0.001
		L	22	19	<0.001
Mickey	Isomorphic	R	23	20	<0.001
		L	15	15	<0.001
Nick	Inverted	R	24	21	<0.001
		L	33	30	<0.001
Solo	Inverted	R	16	16	<0.001
		L	16	8	0.500
Nick	Isomorphic	R	19	19	<0.001
		L	12	10	0.039
Solo	Isomorphic	R	22	22	<0.001
		L	13	12	0.003

sented with this task, but it appeared in all subjects at the time of attainment of criterion at the one-sided titration. Subjects in the isomorphic condition tilted significantly more often in the direction of goal location than in the opposite direction (for both subjects in both directions $P<0.05$ for all binomial tests; see Table 3). In the inverted condition, Nick tilted significantly more in the direction of goal location than in the opposite direction for both goal locations (binomials, $P<0.001$), while Solo tilted significantly more in the direction of goal location when the goal region was located on the right side of the monitor (binomial, $P<0.001$) but not when it was on the left side of the monitor (binomial, $P=0.5$). Therefore, in three of the four series of tilting that were scored for subjects in the inverted condition, tilting occurred significantly more often toward the direction of goal location than the direction of required hand movement (see Table 3).

Discussion

Confirming previous findings that capuchins can utilize joystick-testing systems, all four capuchin monkeys achieved criterion for mastery of the joystick (Filion et al. 1994; Jorgenson et al. 1993). These monkeys mastered this task in the isomorphic condition when joystick movement and cursor displacement were directionally locked, and when the joystick was rotated 180° (resulting in cursor displacement in the opposite direction of joystick movement). Contrary to our prediction, the animals that initially experienced the inverted condition mastered the task in a comparable number of trials to the animals in the isomorphic condition. This suggests that the directional relationship between joystick movement and cursor displacement does not affect overall rate of acquisition. This finding is contrary to work done with chimpanzees using televised images to locate objects as well as findings from investigations of human aviators, chimpanzees, and capuchins utilizing joystick-testing systems that suggest that an isomorphic relationship facilitates learning (Jorgensen 1995; Menzel et al. 1985; Poulton 1966, 1974). Our findings lend support to the view that the directional relationships between physical action and resultant object movement are learned associatively. In other words, all directional relationships between action and resultant motion should be learned by capuchins in comparable numbers of trials.

We observed that the proportion of trial length spent visually tracking the cursor covaried positively with skill development in three of the four subjects. The fourth subject tracked the cursor at a rate comparable to that of the other subjects at overall joystick mastery when attaining criterion for mastery of the four-sided titration. This subject maintained this level of tracking throughout skill development. Therefore, this subject was tracking at a high rate beginning from attainment of criterion at the four-sided titration and across acquisition. By tracking the cursor's movement on the screen, subjects could learn that the joystick controlled the cursor and the directional link between them.

Following their mastery of the task in the inverted condition, two subjects remastered the task in the isomorphic condition. Since knowledge of the joystick–cursor relationship was already in place prior to the reversal, we expected these animals to track significantly more at mastery of the four-sided titration during reversal than they did at the same point in mastery of the inverted condition. Our findings supported this prediction. Once an animal learned to use the information provided by the computer screen it continued to do so, even if critical task parameters were altered.

Following the same line of reasoning, we predicted that subjects that underwent the reversal would master the isomorphic condition in fewer trials than they did the inverted condition, and that they would do so in fewer trials than it took the two other subjects initially assigned to the isomorphic condition. Our findings supported both of these predictions. Subjects that underwent the reversal mastered the isomorphic condition in fewer trials than it took them to master the inverted condition and fewer trials than it took those animals exposed only to the isomorphic condition. Therefore, not only are these animals retaining the behavior of cursor tracking when task parameters are changed but they are also retaining other task knowledge.

Consistent with the findings of C.M. Filion et al. (unpublished data), all subjects demonstrated a postural tilt of the body while mastering the use of the joystick. This tilt was absent at the four-sided criterion but appeared in all subjects by the time they attained the one-sided criterion. Thus, this behavior is not intrinsic to the task but does appear to aid subjects in their mastery. Subjects that underwent the reversal continued to demonstrate the body tilt following this alteration of the joystick–cursor relationship. We sought to determine which factor of the task (goal location or direction of joystick movement) governed the direction of the tilt, by examining the tilts of subjects in the inverted condition. In this case a goal located on the right of the monitor would require a hand movement on the joystick to the left. In three of the four cases (2 subjects in inverted condition x2 directions of goal location) the subjects tilted significantly more in the direction of goal location than direction of required joystick movement. These results tentatively suggest that direction of tilt reflects attentional demands of the task and not its motoric requirements.

We found no literature on postural body tilts in skill acquisition or performance in humans even though this behavior can be observed in a number of everyday situations. For example, consider the body tilt that occurs when a bowler watches the ball traverse the lane, when a golfer strikes a putt and watches it move to the cup, after a tennis player strikes a shot that is approaching the boundary lines, or even when a person is playing a video game. All of these situations, as well as the one we addressed here, share one key commonality: that the actor tilts when out of direct physical contact with the object that he or she is acting upon. In the case of the bowler, the tilt occurs after the ball has left the hands and as it is approaching the pins. It appears that the tilt occurs as "an attempt to steer" the ball away from the gutters and toward the center pin. For the golfer, the tilt occurs after the club strikes the ball and as the ball is moving to the cup. In this case, it seems that the tilt occurs in a manner consistent with an attempt to steer the ball into the cup. A similar situation occurs with the tennis player. The tilt occurs after the player strikes the ball with the racket and as the ball is moving out of bounds, thus giving the appearance that the player is attempting to direct the ball to drop inside the line and not sail beyond. Finally, in the case of children playing video games and monkeys learning to utilize a joystick to control a cursor on a screen, we believe the tilt is an attempt to control a situation in which there is not a direct physical connection between their action and the movement of the target object.

Tilting is observed to occur in sports situations after loss of contact with the object but while waiting for the final outcome. The same appears to occur when tilting while using video systems. The subjects or players can act upon the joystick to control movement on the screen but are not directly displacing the cursor physically (by placing their hand or joystick directly on it). We believe that body tilting in joystick tasks is a reflection of the spatially disjointed nature of the tasks. The tilt occurs when the object receiving the action is out of direct physical contact with the actor and prior to movement outcome. From a dynamic systems perspective, the production of a body tilt may serve to enlarge (or perhaps deepen) the perceptual-motor workspace (Newell 1991). By altering the position of the body with a tilt, individuals create additional kinesthetic stimulation in a situation where proprioceptive stimulation is not being provided by the goal or target object (i.e. the ball in sports or goal region on the computer monitor).

To test the notion that tilting reflects a lack of direct physical control of the object acted upon at the time of outcome, one might compare skill acquisition using three versions of computer-mediated testing systems. We would first want to replicate our results in naive animals using the joystick-mediated system. Second, we would want to see if tilting is also present in animals learning to control a cursor on a screen using a rollerball interface. This system would present the subject with the same form of spatial displacement of action from outcome that is present in the joystick-mediated system. Because of the similar nature of the joystick and rollerball systems, we would expect tilting to be present in subjects mastering and utilizing the rollerball system. Finally, to test that it is the disjointed nature of the system setup that governs tilting behavior, one could train naive subjects to use a touch screen system to bring a cursor in contact with a goal region. Since this system would allow for direct action upon the target object as well as direct physical control at time of outcome, we predict that body tilting would be absent in subjects mastering this paradigm.

Computerized testing systems provide us with a new and interesting medium with which to document skill acquisition. Several interesting questions about the acquisition of skill in these systems remain to be addressed. For example, it would be worthwhile to analyze errors during the acquisition of this skill, and to document how the behaviors of tracking and tilting are altered during or following joystick movement errors. One could address the questions of how tilts are distributed when the cursor is moved away from the goal region (vs toward the goal region), and whether the subjects track the cursor during these erroneous movements. To simplify such an analysis one could restrict the movement of the joystick using a T-shaped template such that movements toward and away from the goal are clearly defined. Alternatively, one could conduct a detailed path analysis of joystick movements to determine how far each path deviates from an "optimal" or path of minimum distance (see Menzel et al. 2001). It is evident that many other permutations of skill and task are possible using this testing system. Thus, not only are these computerized testing systems providing us with new insight into the cognitive abilities of humans and nonhumans but they provide us with an interesting and timely medium by which to examine perceptual-motor skill.

In sum, we have shown that capuchin monkeys are capable of skilled manipulation of a joystick to direct a cursor on a computer monitor under both isomorphic and inverted directional relationships. Previous knowledge of task parameters facilitated performance for those animals that underwent a reversal of the directional relationship following initial task mastery. In our documentation of the natural history of this skill, we observed that visual tracking of the cursor on the monitor increased with proficiency at this task. Subjects maintained this higher proportion of trial length spent tracking the cursor when undergoing the directional reversal following initial task mastery. Thus, these subjects had learned that tracking was an effective way of gaining information from the two-dimensional environment. Finally, subjects were observed to tilt their bodies while manipulating the joystick, much like that which we see in human users. This tilt was observed to increase with skill development and we have tentative evidence that the tilt is governed by goal location rather than direction of required joystick movement. This suggests that the postural adjustment reflects some aspect of the cognitive/perceptual process rather than being the result of a motoric demand of the task.

Acknowledgements We thank Christine Orman, Sarah Cummins-Sebree, and Kai McCormack for their assistance in experimental design, data collection, and analysis. We thank the University of Georgia Instrument Shop for the construction of our apparatus. We are grateful to Patrick Ulam for programming assistance, as well as David Washburn and colleagues at the Language Research Center of GSU for programming modifications and hardware. This work was supported by grant no. CHD06106 from the National Institutes of Health of the United States to Georgia State University.

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